New Opportunity to Evaluate the Warm Rain Formation Process in Global Climate Models with A-Train Observations

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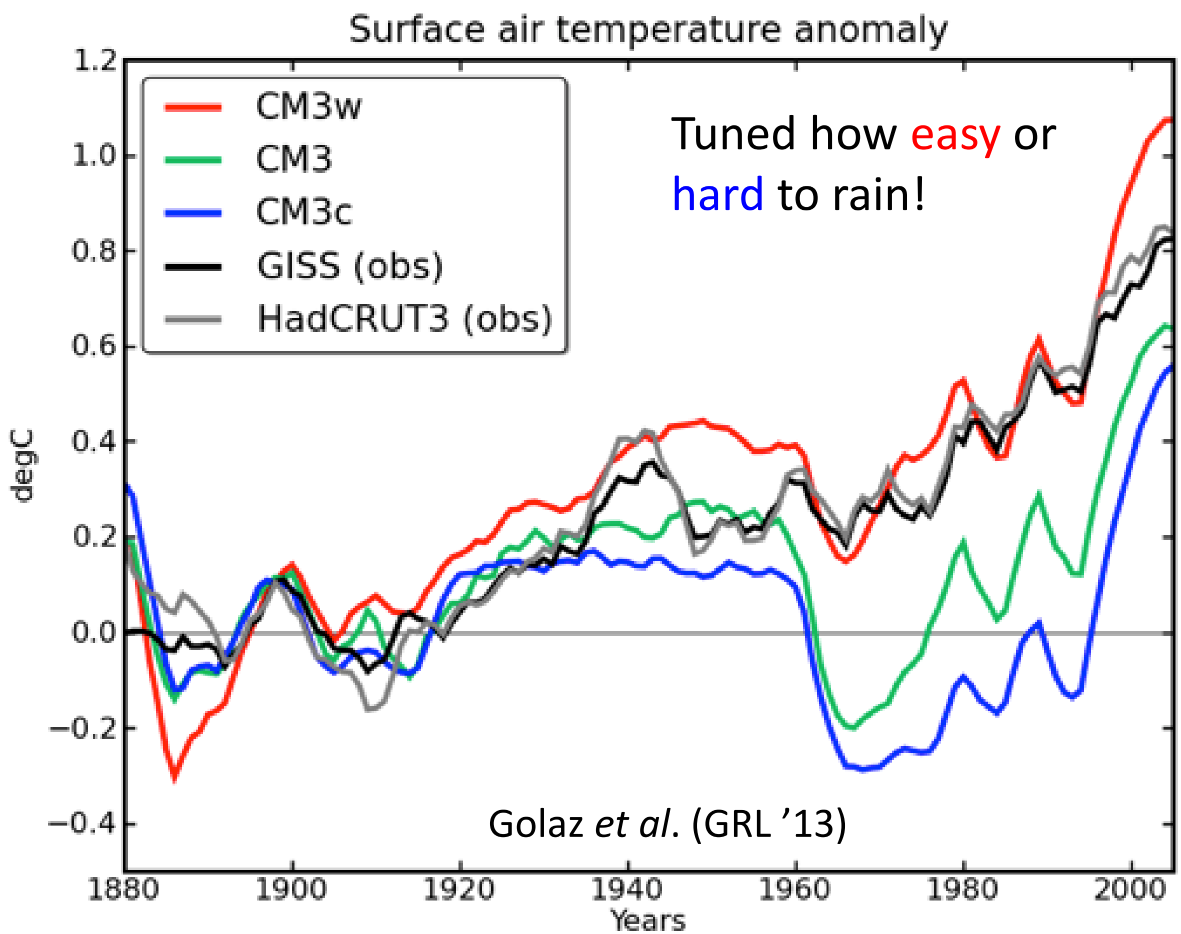
Introduction: Why are warm rain clouds important?



Rain occurs when r=6.0μm
➔ Best temperature trend.

Rain occurs when r=10.6μm
➔ Threshold particle radius is close to observation.

❖ Climate model reproduces the correct temperature trend only with flawed model physics.

Introduction: Why are warm rain clouds important?

Dreary state of precipitation in global models

Graeme L. Stephens,[1] Tristan L'Ecuyer,[1] Richard Forbes,[2] Andrew Gettlemen,[3] Jean-Christophe Golaz,[4] Alejandro Bodas-Salcedo,[5] Kentaroh Suzuki,[1] Philip Gabriel,[1] and John Haynes[6]

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[1] New, definitive measures of precipitation frequency provided by CloudSat are used to assess the realism of global model precipitation. The character of liquid precipitation (defined as a combination of accumulation, frequency, and intensity) over the global oceans is significantly different from the character of liquid precipitation produced by global weather and climate models. Five different models are used in this comparison representing state-of-the-art weather prediction models, state-of-the-art climate models, and the emerging high-resolution global cloud "resolving" models. The differences between observed and modeled precipitation are larger than can be explained by observational retrieval errors or by the inherent sampling differences between observations and models. We show that the time integrated accumulations of precipitation produced by models closely match observations when globally composited. However, these models produce precipitation approximately twice as often as that observed and make rainfall far too lightly. This finding reinforces similar findings from other studies based on surface accumulated rainfall measurements. The implications of this dreary state of model depiction of the real world are discussed.

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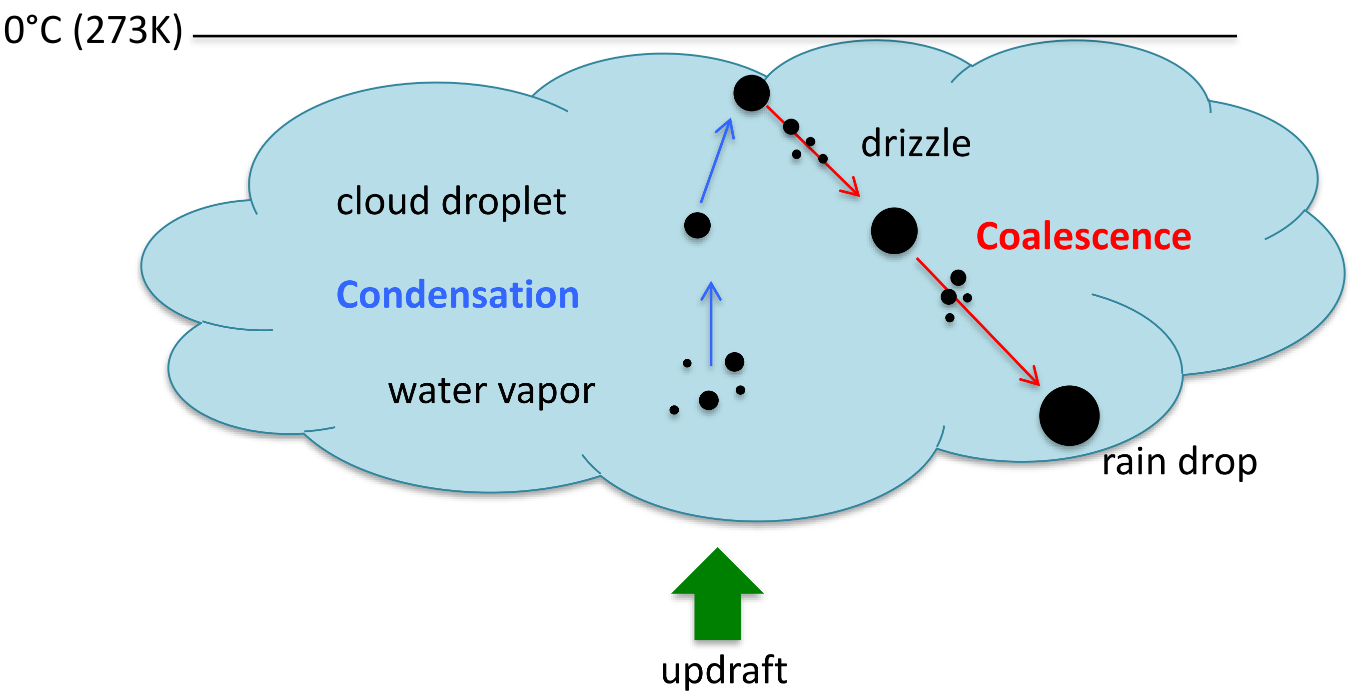
Models make too much light precipitation!

- Detailed observations of microphysical processes in real clouds is needed to improve models.

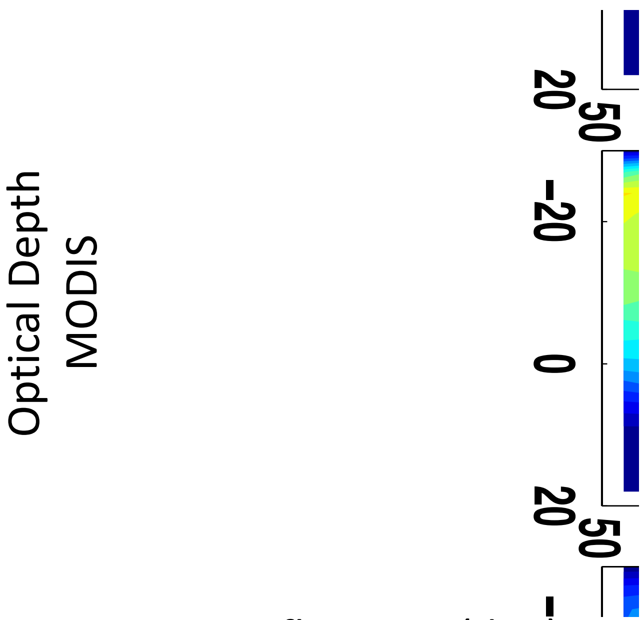
Introduction: How does warm rain form?

- The warm rain formation process generally starts by **condensation**. Once the particle becomes large enough, the **coalescence** process begins.



Method: Contour Frequency of Optical Depth Diagram (CFODD)

Cloud top particle size
5-10µm (MODIS)

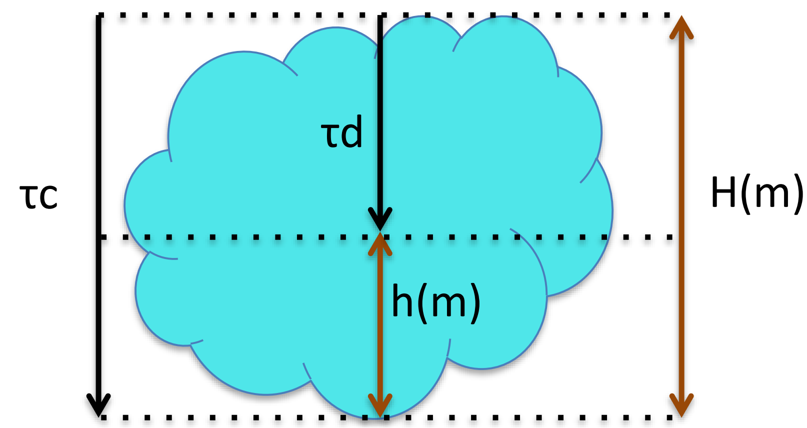


Reflectivity (dBZ)
CloudSat CPR

Optical depth (a measure of how opaque a cloud is):

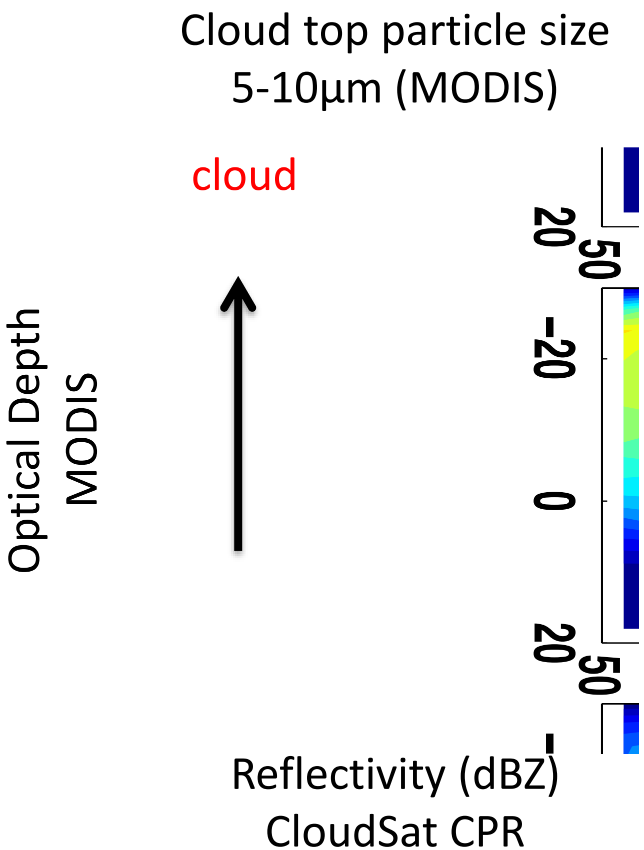
$$\tau_d(h) = \tau_c \left[1 - \left(\frac{h}{H} \right)^{5/3} \right]$$

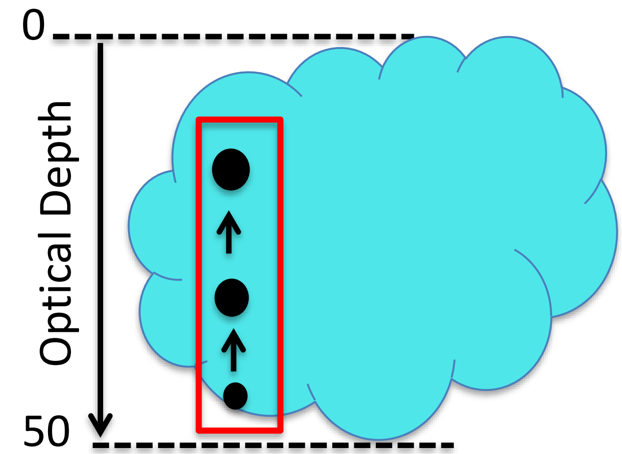
where τ_c is total optical depth, and H is geometric thickness (Suzuki et al., 2010).



This equation is derived based on the concept of the adiabatic-condensation growth model (e.g., Brenguier et al., 2000; Szczodrak et al., 2001).

Method: Contour Frequency of Optical Depth Diagram (CFODD)





cloud mode (<-15dBZ) ➔ drizzle mode (>-15dBZ & <0dBZ) ➔ rain mode (>0dBZ)

- Stage of condensation

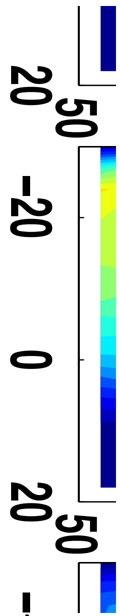
Method: Contour Frequency of Optical Depth Diagram (CFODD)

cloud top particle size

5-10µm 10-15µm

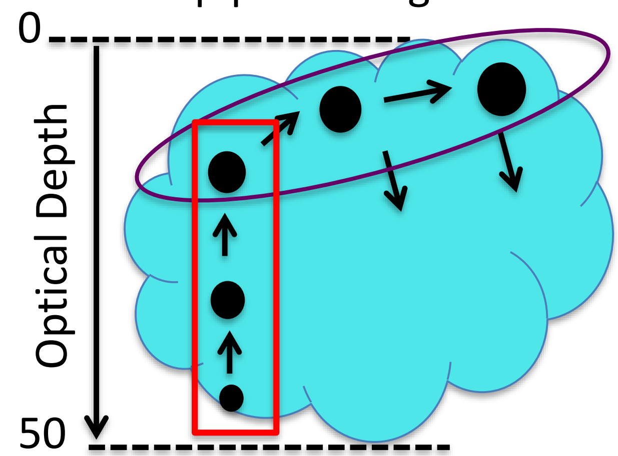
cloud

Optical Depth
MODIS



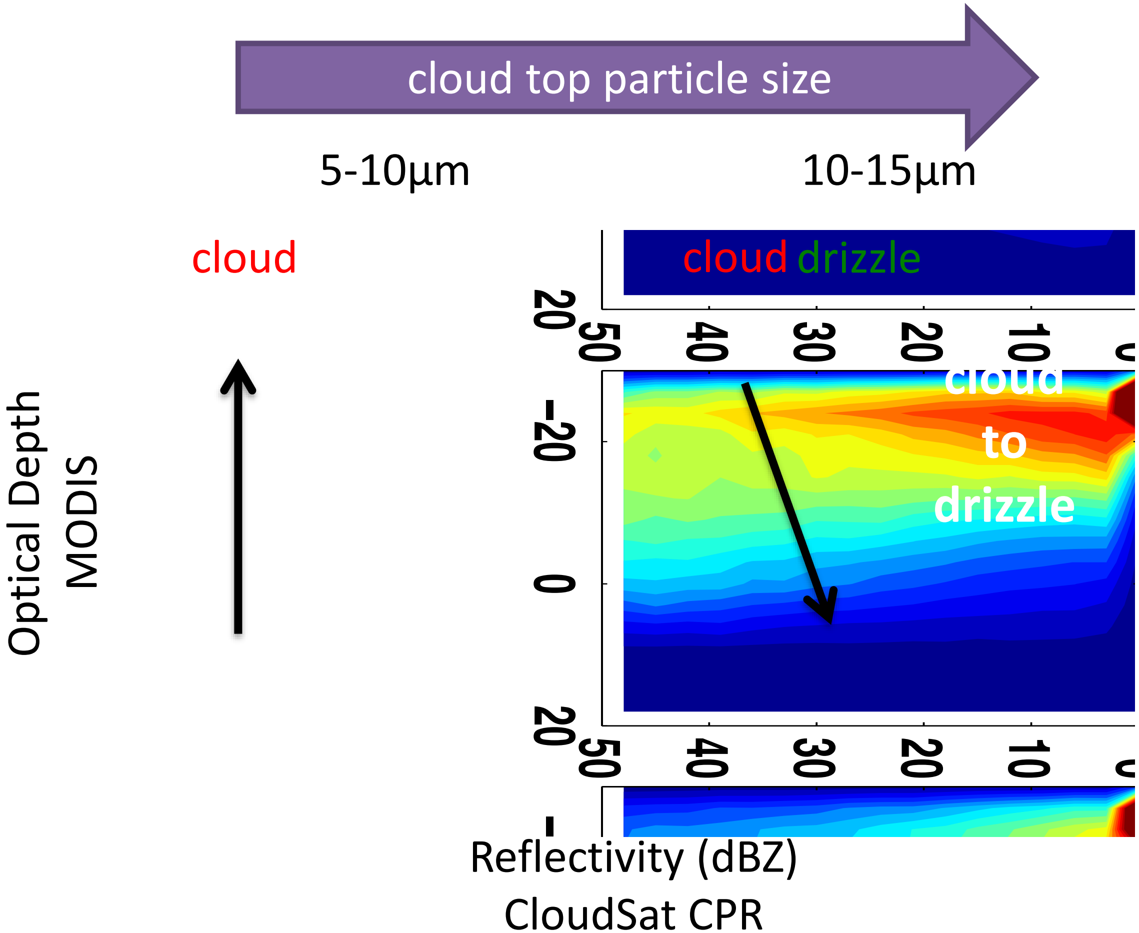
Reflectivity (dBZ)
CloudSat CPR

- As clouds age, cloud top particles grow



cloud mode (<-15dBZ) ➔ drizzle mode (>-15dBZ & <0dBZ) ➔ rain mode (>0dBZ)

Method: Contour Frequency of Optical Depth Diagram (CFODD)



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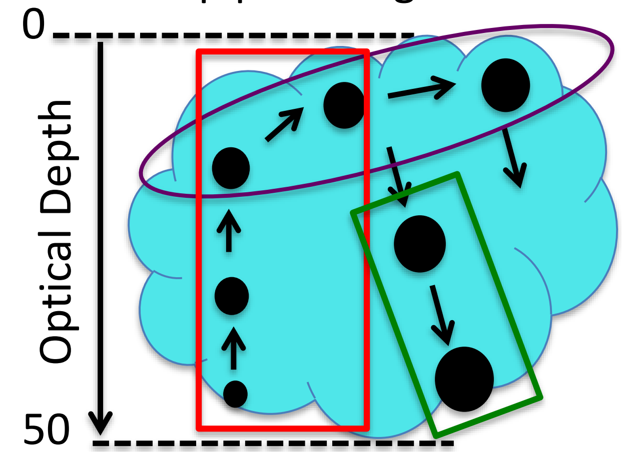

cloud mode (<-15dBZ) ➔ drizzle mode (>-15dBZ & <0dBZ) ➔ rain mode (>0dBZ)

- Stage of coalescence

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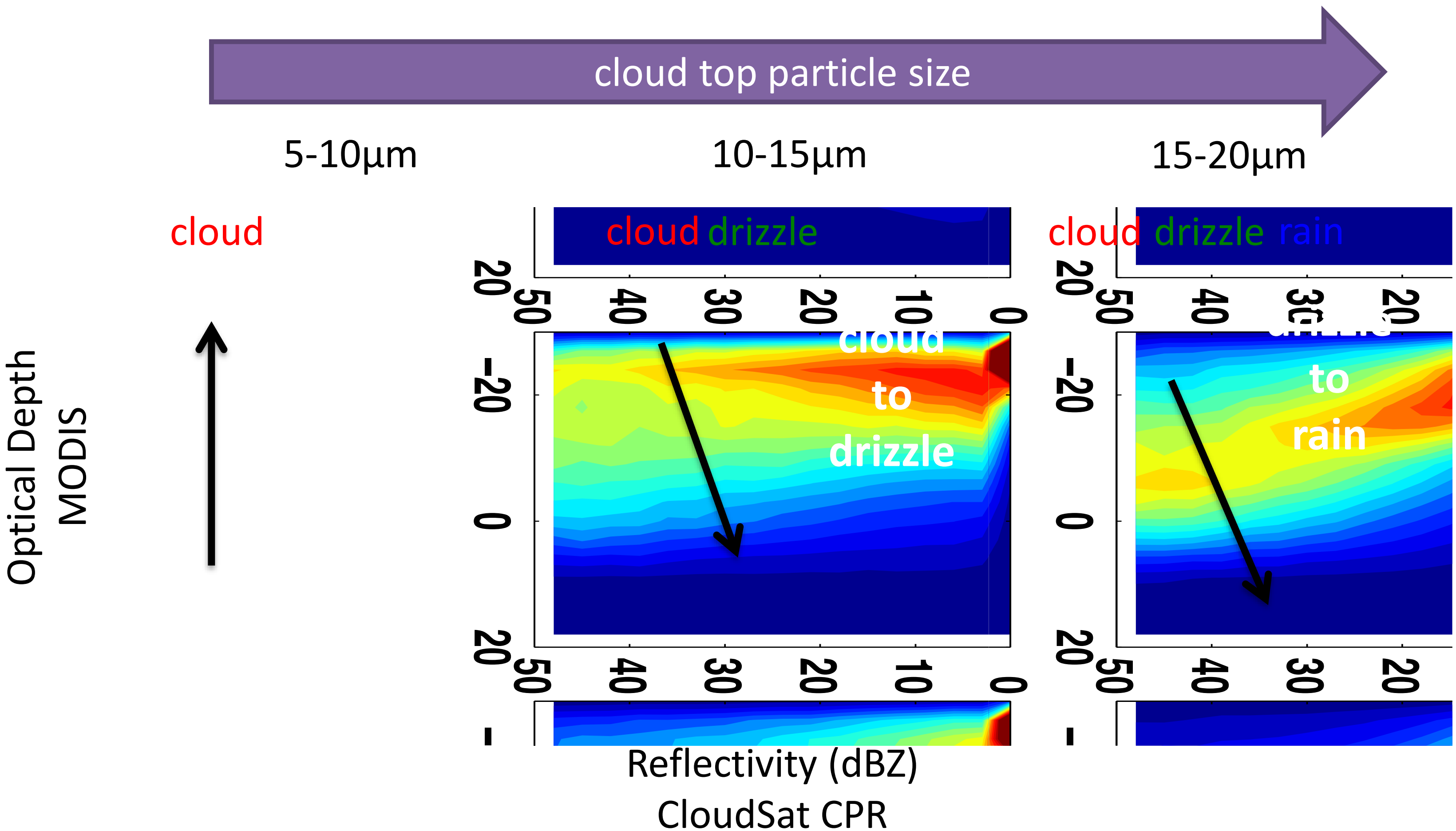
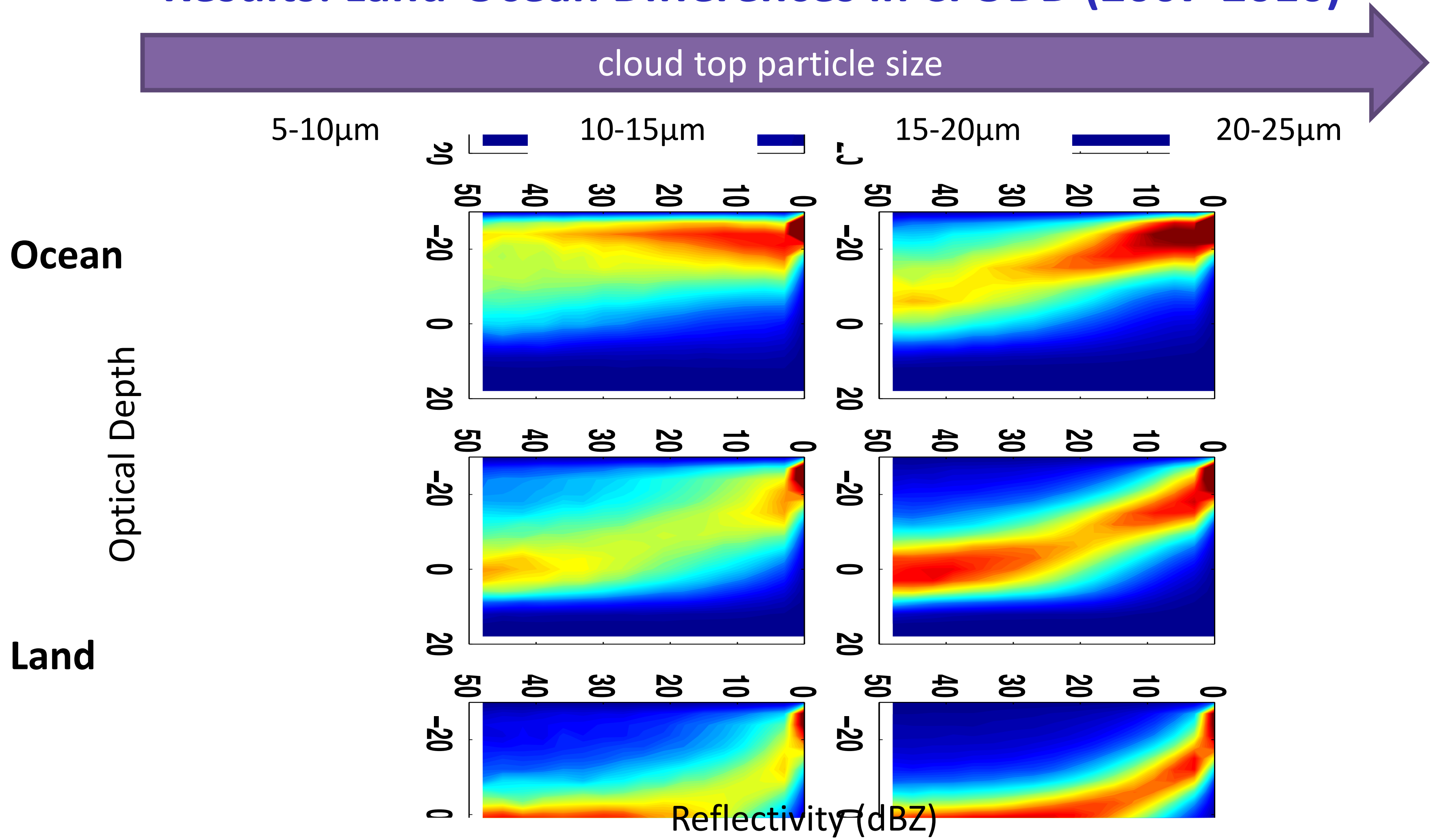


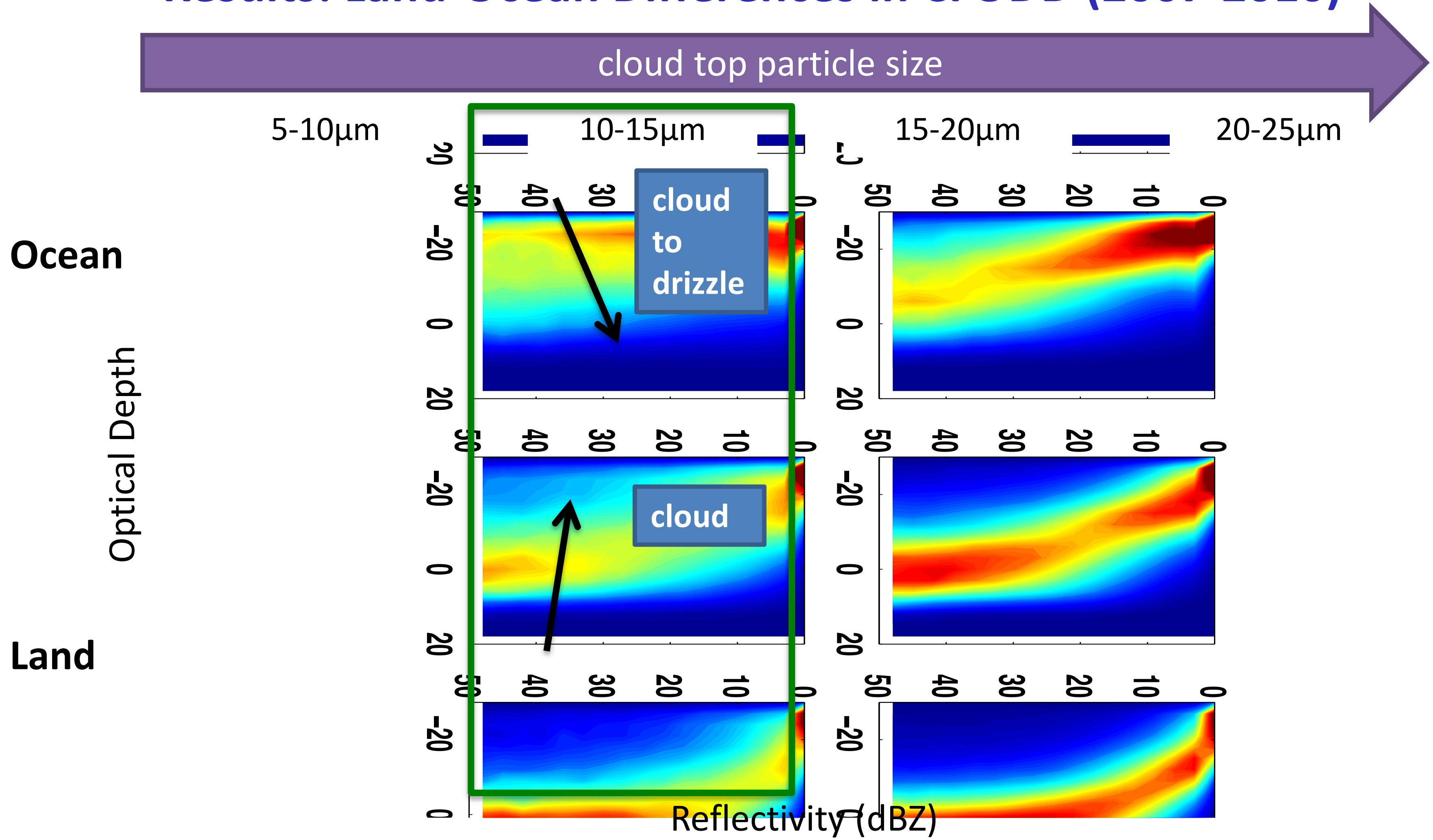
cloud mode (<-15dBZ) ➔ drizzle mode (>-15dBZ & <0dBZ) ➔ rain mode (>0dBZ)

- Stage of coalescence

Results: Land-Ocean Differences in CFODD (2007-2010)

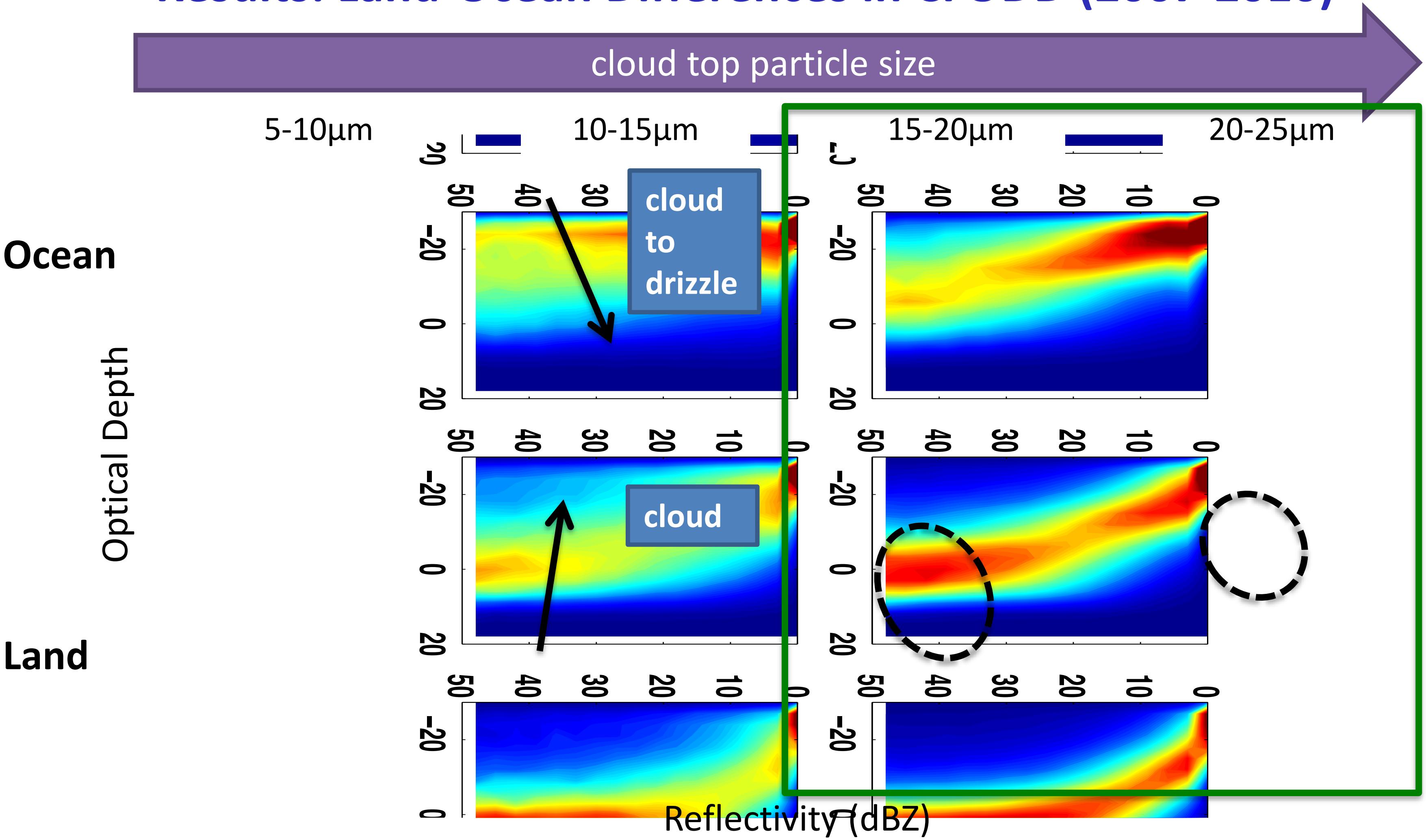


Results: Land-Ocean Differences in CFODD (2007-2010)



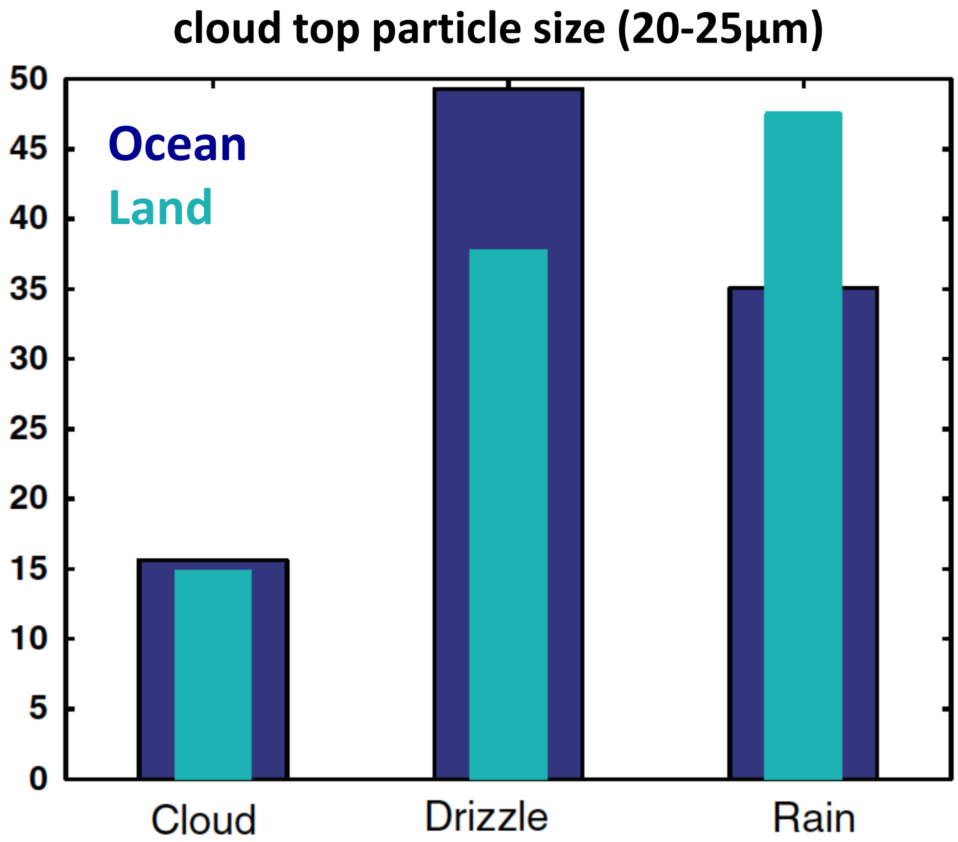
- Particles start to fall sooner over ocean.

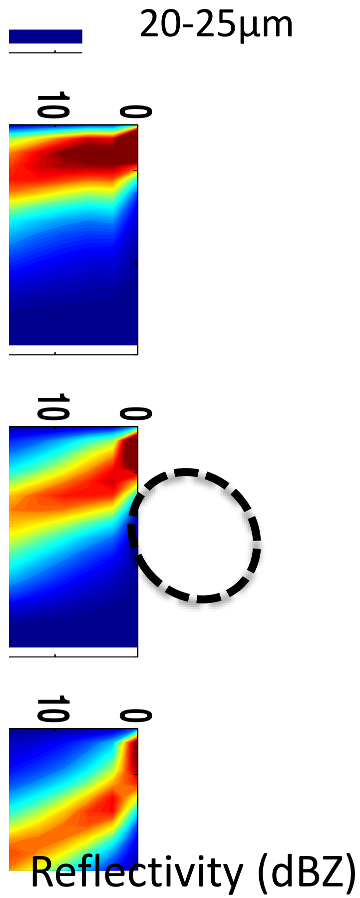
Results: Land-Ocean Differences in CFODD (2007-2010)



- Particles start to fall sooner over ocean.
- A “drizzle gap” can be seen over land.

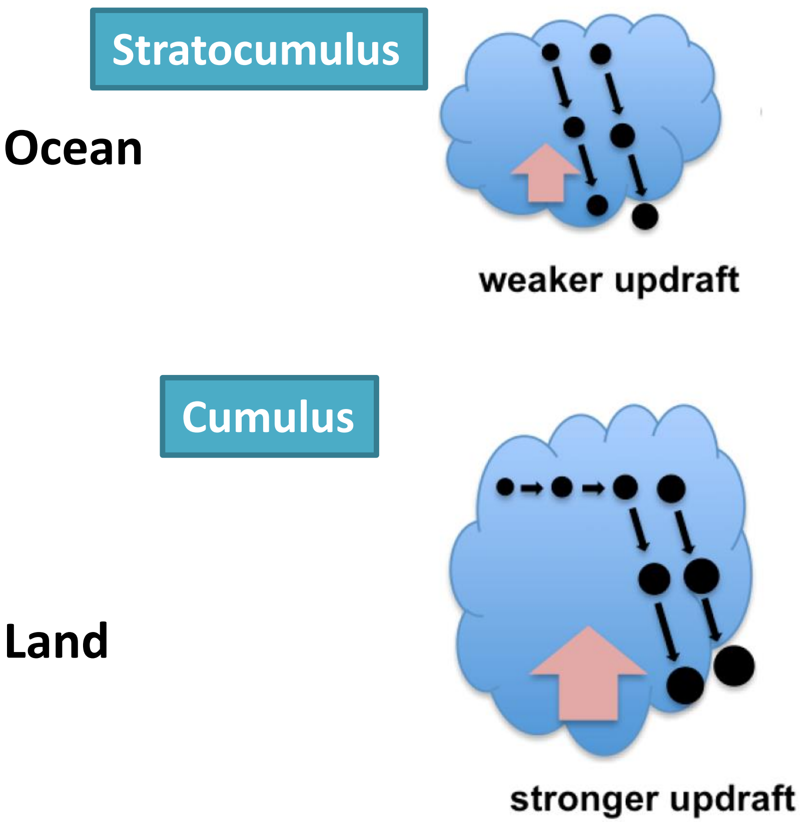
Results: Land-Ocean Differences in CFODD (2007-2010)

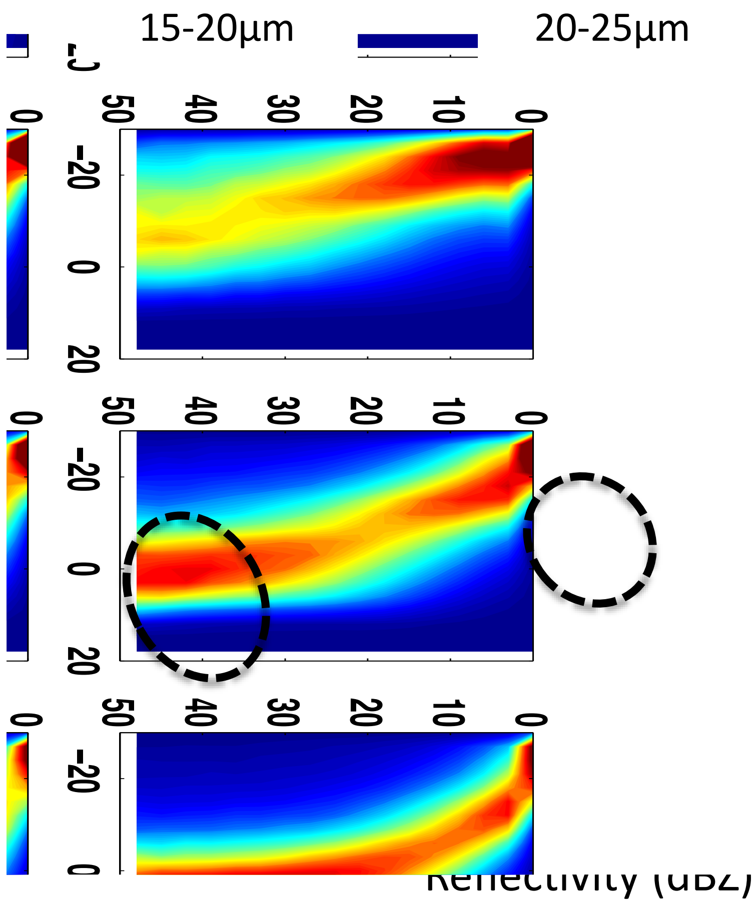




❖ A “drizzle gap” can be seen over land (drizzle suppression).

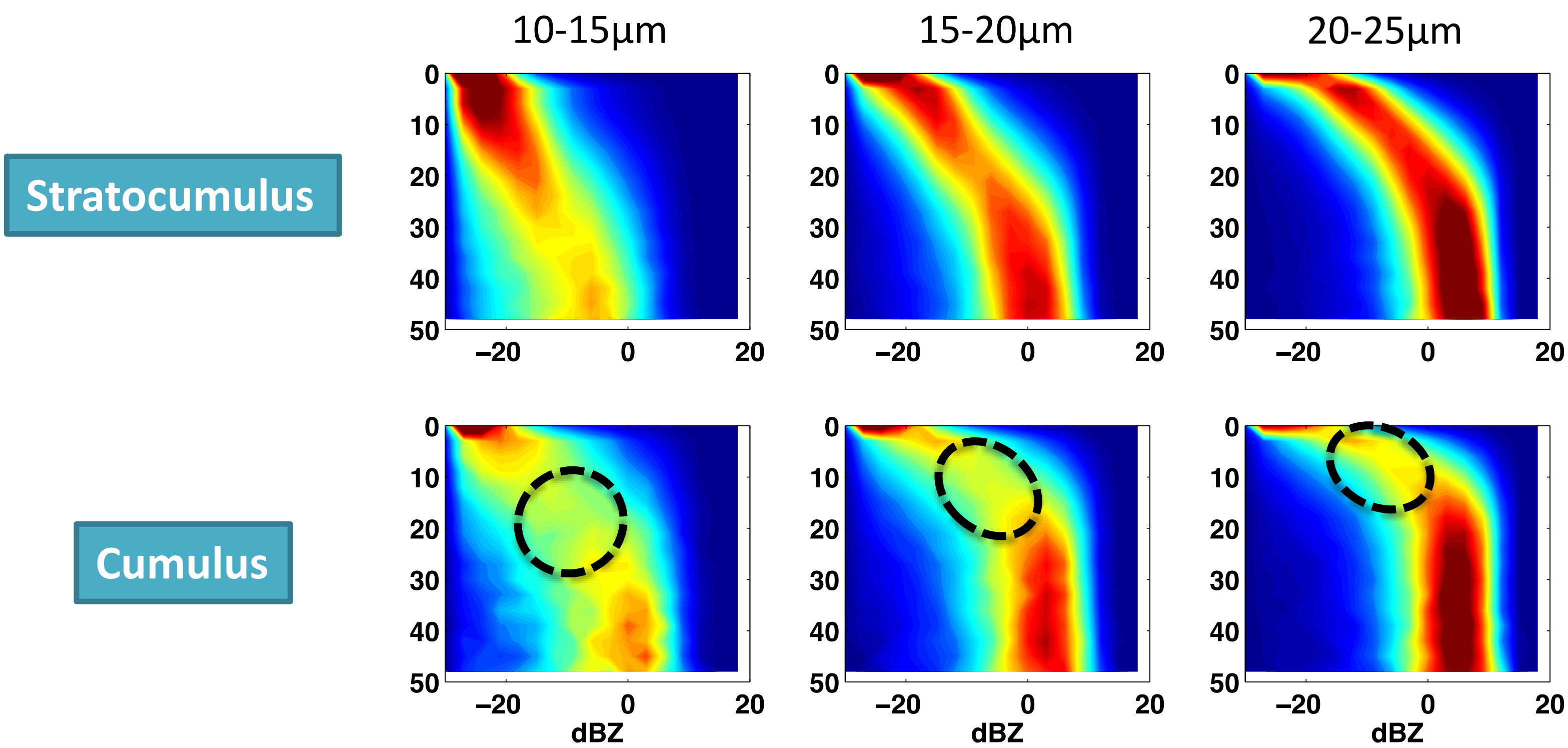
Hypothesis: The land-ocean differences are due to the land-ocean differences in the intensity of updraft (Nakajima et al, 2010).



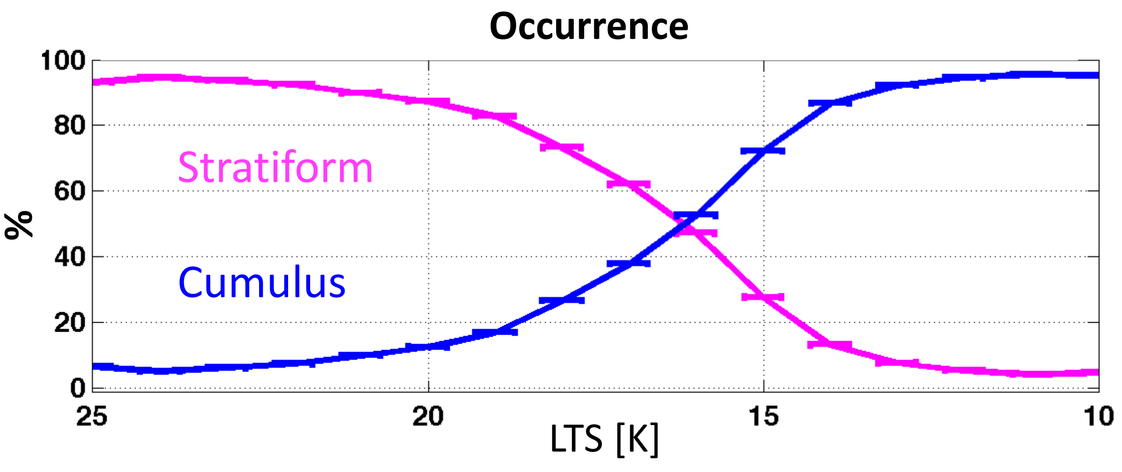


- Particles start to fall sooner over ocean.
- A “drizzle gap” can be seen over land (drizzle suppression).

Results: Stratocumulus vs. Cumulus over Ocean

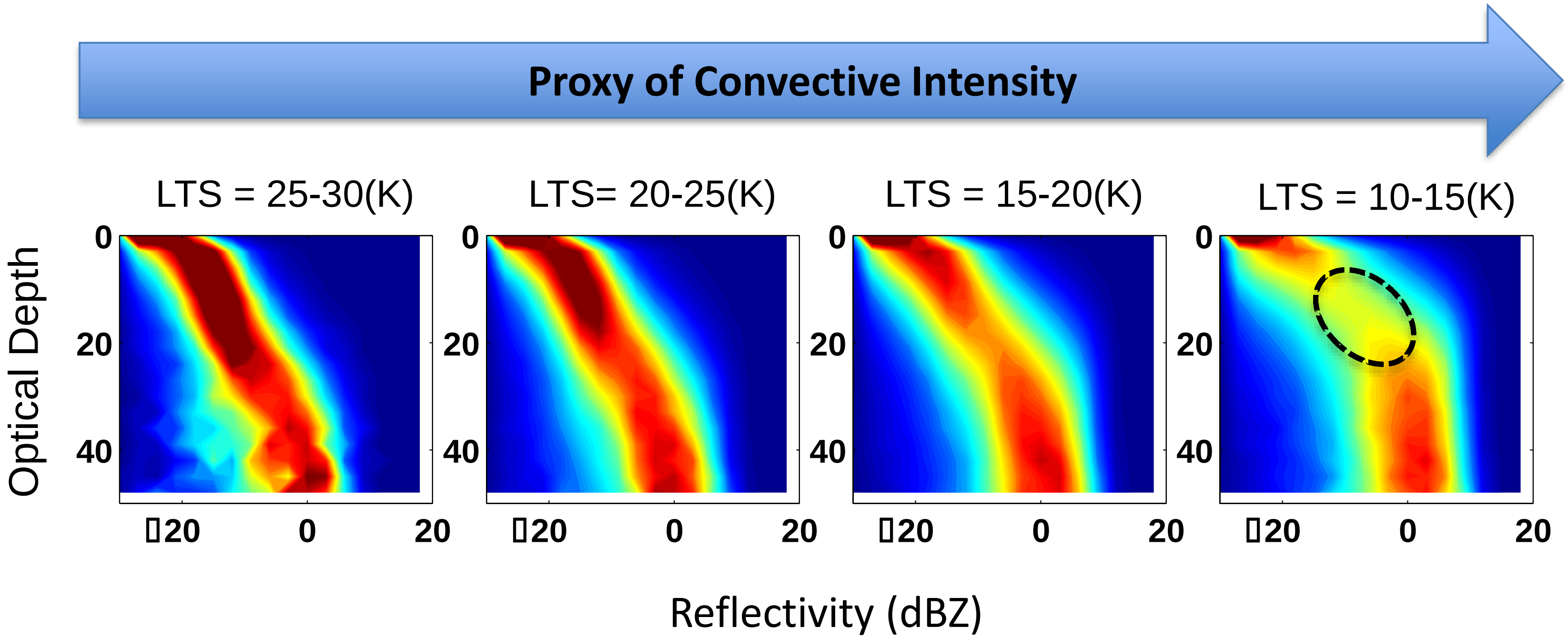


LTS: Lower Tropospheric Stability
➔ Difference in potential temperature between the 700hPa and the surface.



Testing Our Hypothesis I: A-Train Observation over Ocean (2007-20010)

Cloud top particle size: 15-20µm



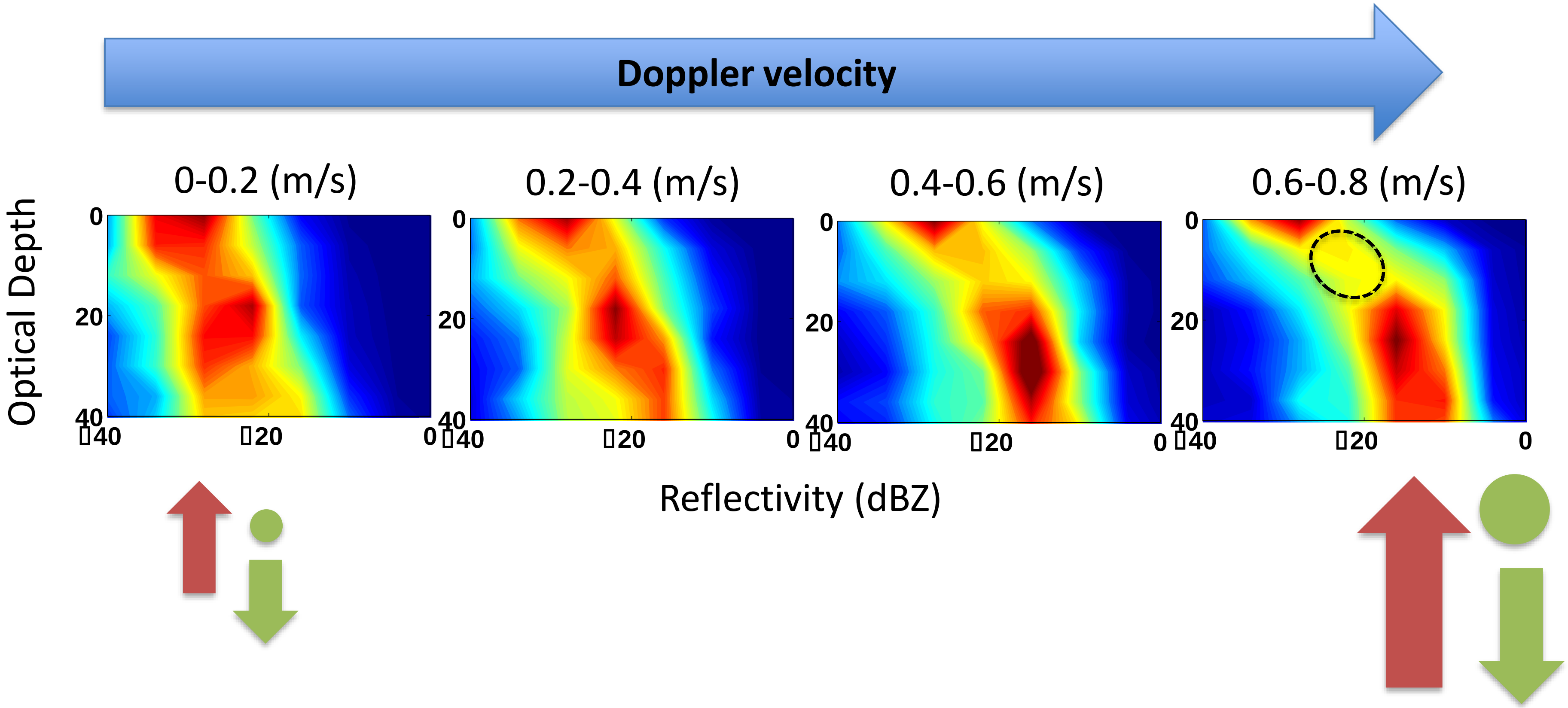
Likely to have weaker updraft (i.e., ocean, St, Sc)

Likely to have stronger updraft (i.e., land, Cu)

- “Drizzle gap” is significant when LTS is lower.

Testing Our Hypothesis II: ARM Observation, Azores Portugal (2009-2010)

Cloud top particle size: 15-20µm

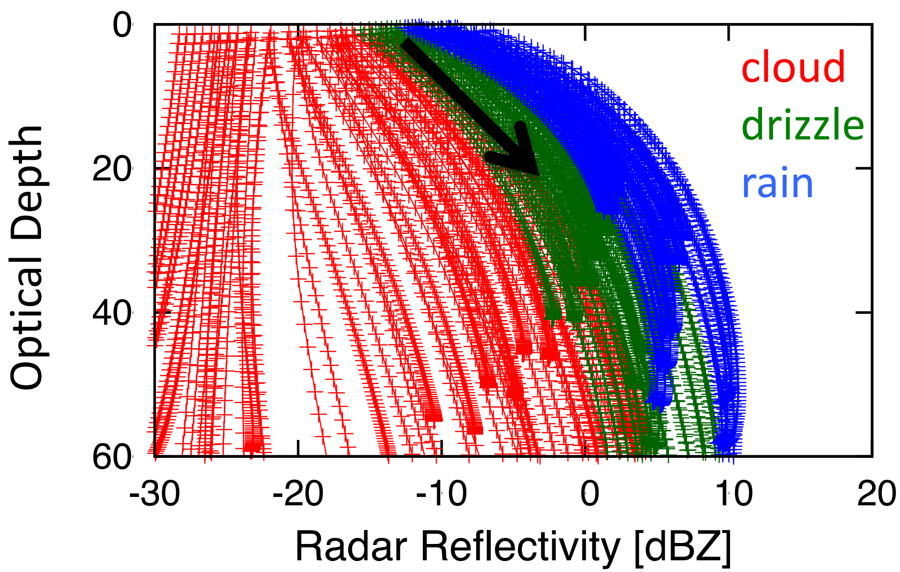


- Doppler velocity is the sum of both the updraft and the falling drop velocities.
- However, knowing the reflectivity and Doppler upward motion together provides a clearer index of upward strength.
- “Drizzle gap” starts to appear when Doppler velocity is stronger.

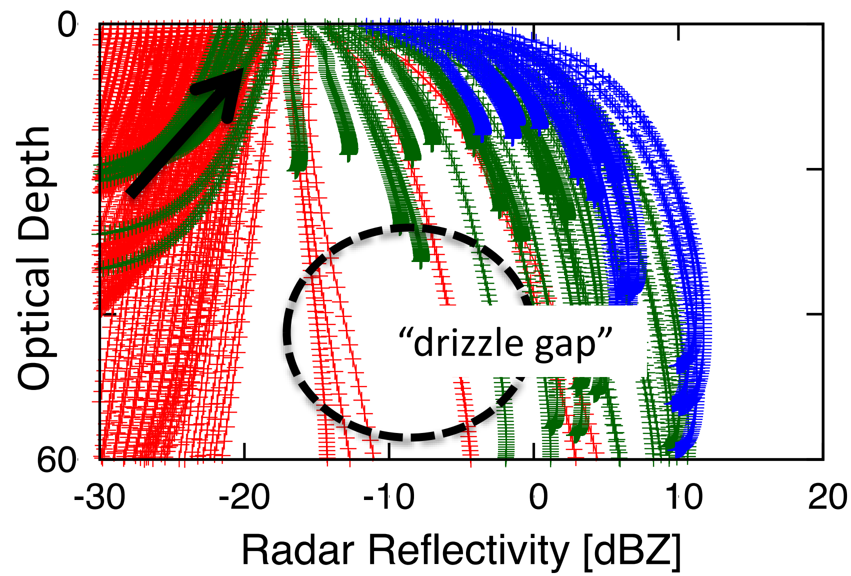
Testing Our Hypothesis III : Bin Microphysics Model Simulation

Vertical velocity

0.3 (m/s)

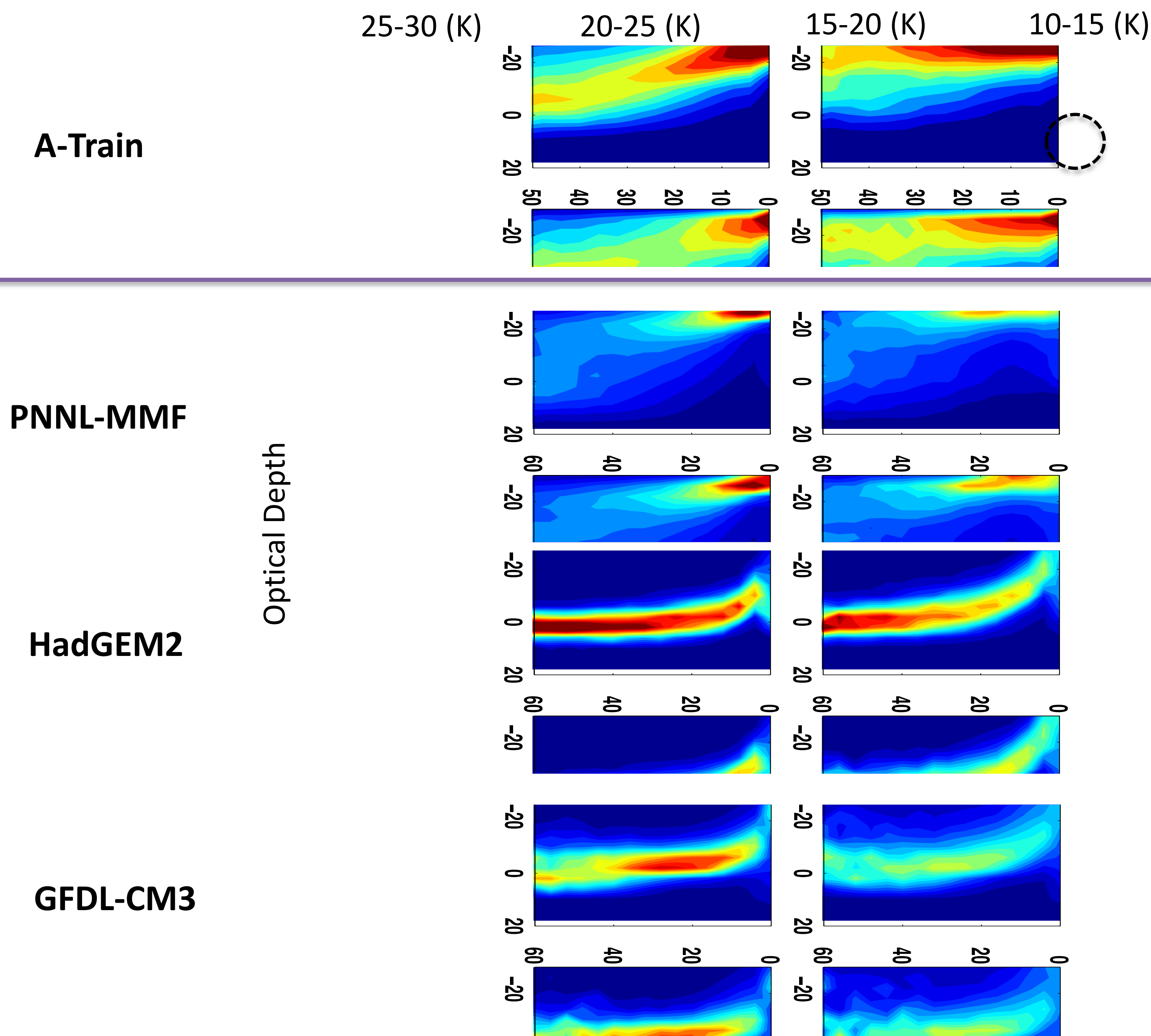


0.7 (m/s)

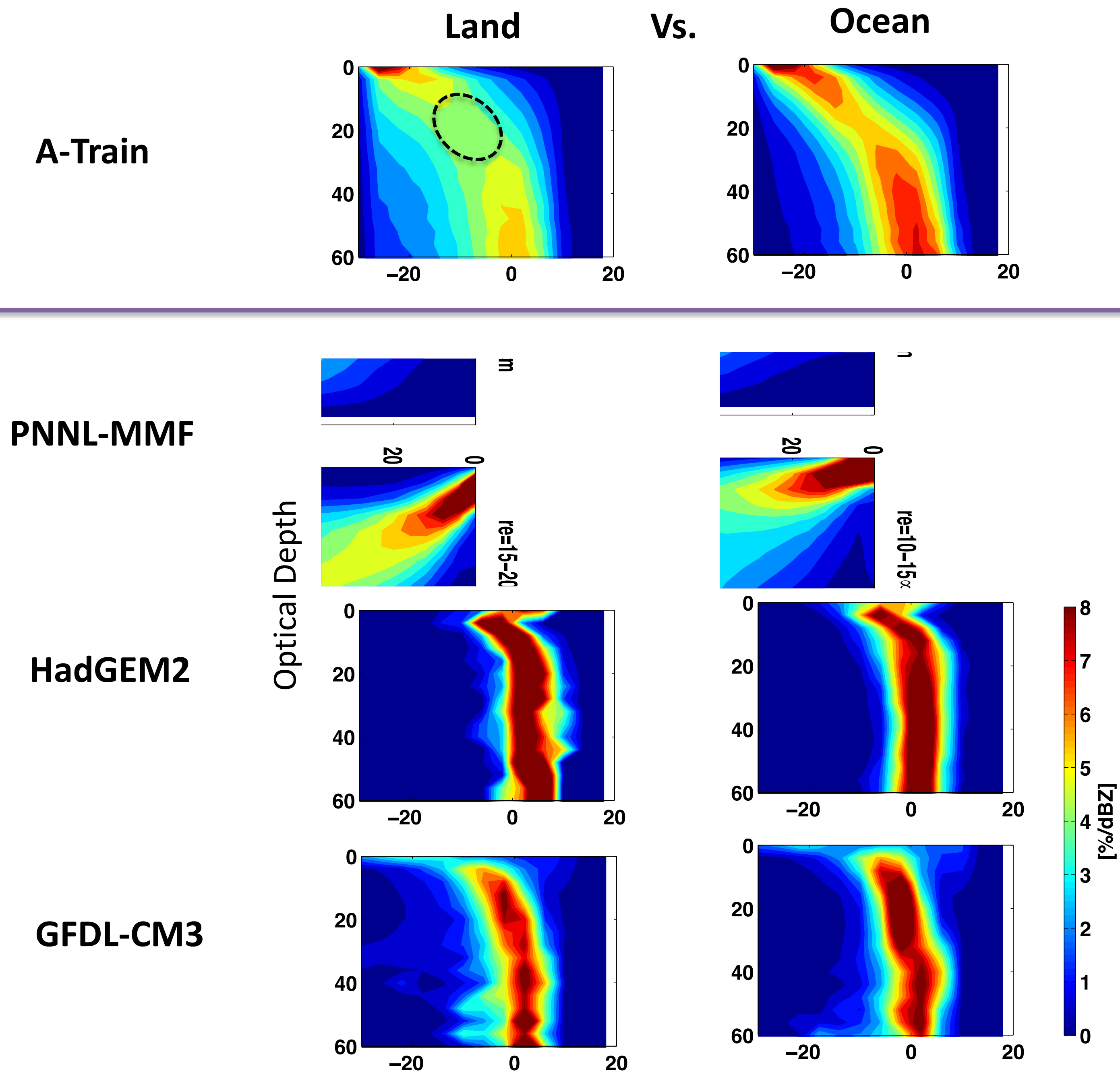


- Particles start to fall sooner over weak updraft.
- Physical model confirmed the nature of the “drizzle gap”.

LTS dependence in GCMs (Re: 15-20μm)



Land-Ocean Difference in GCMs (Re: 15-20μm)



Summary

- Observations expose the land-ocean differences in the warm rain formation process.
  - Environmental condition(e.g., intensity of updraft) plays a key role in the warm rain formation process.

- GCMs **do not** expose the land-ocean differences.
  - There is little link between environmental condition and cloud microphysics.

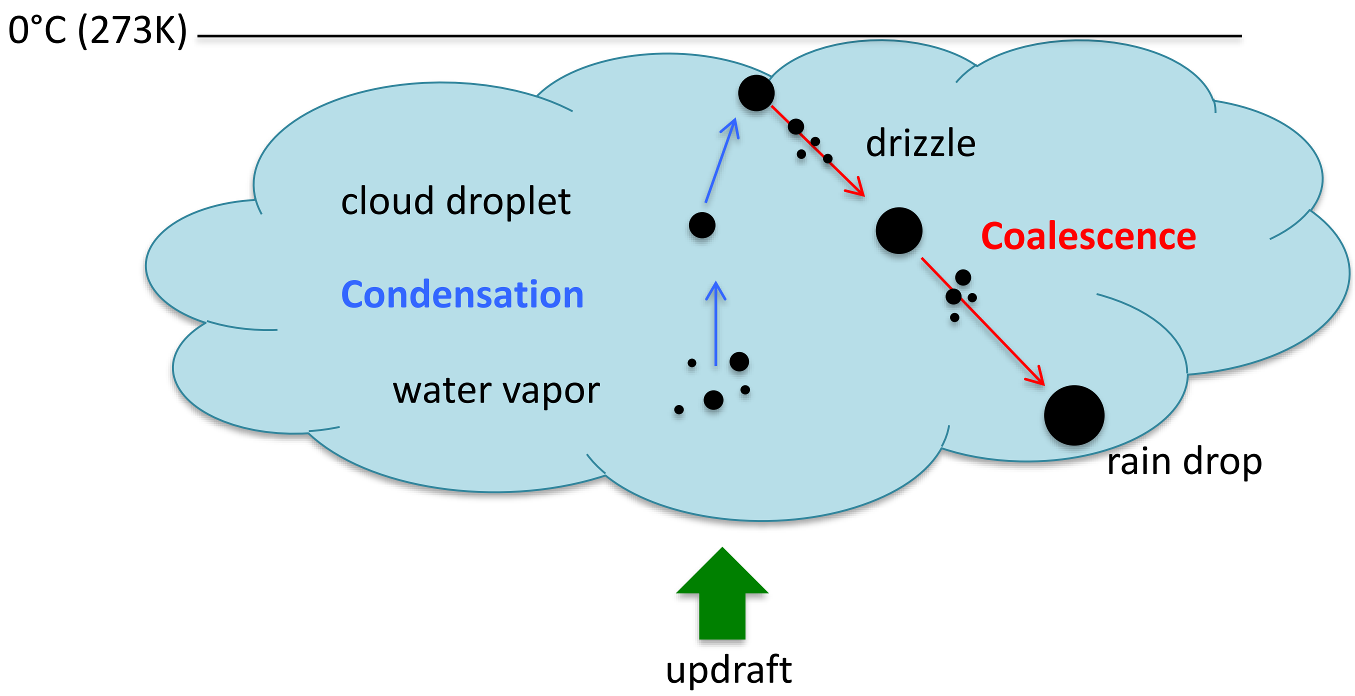
Reference:
Takahashi, H., Suzuki, K., & Stephens, G. (2017). Land–ocean differences in the warm-rain formation process in satellite and ground-based observations and model simulations. *Quarterly Journal of the Royal Meteorological Society*, *143*(705), 1804-1815. DOI:10.1002/qj.3042

Thank you!

Introduction: What are warm rain clouds? How does warm rain form?

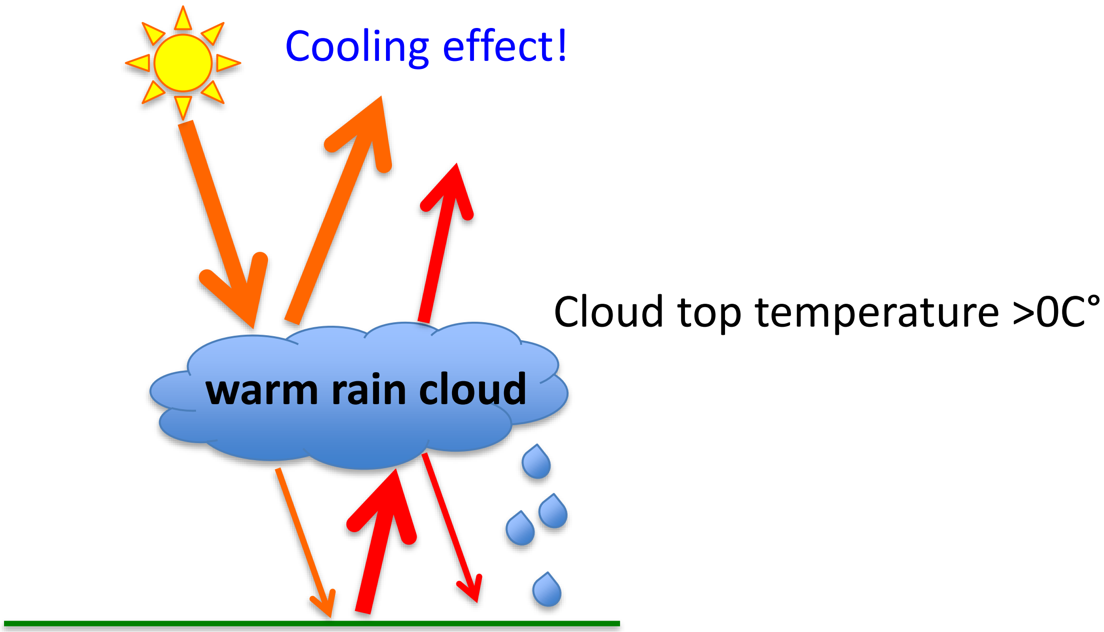
- Warm rain clouds are clouds whose cloud top temperatures are above 0°C .

- The warm rain formation process generally starts by **condensation**. Once the particle becomes large enough, the **coalescence** process begins.



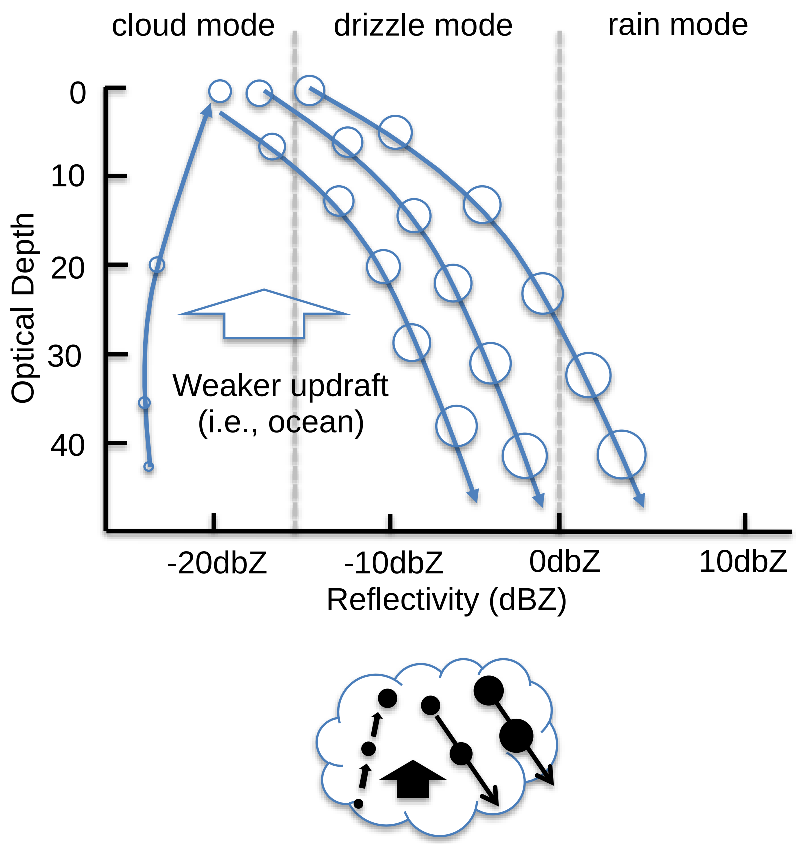
Introduction: Why are warm rain clouds important?

- The cloud-drizzle-rain processes in warm clouds play a key role in controlling the **hydrologic cycles and energy budgets.**
  - Warm rain clouds are responsible for ~30% of the total rainfall in the Tropics.
  - Warm rain clouds **strongly reflect solar radiation** back to space.
- **Climate projections are very sensitive to the warm-rain formation process.**

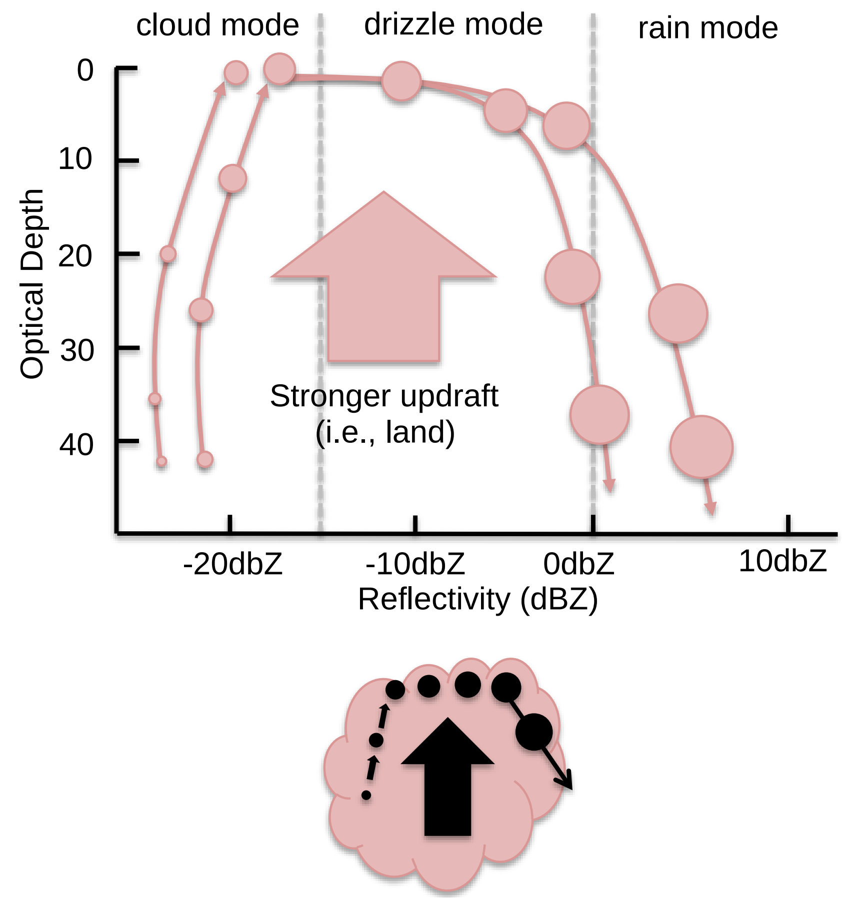


Hypothesis: The land-ocean differences are due to the land-ocean differences in the intensity of updraft (Nakajima et al, 2010).

Weaker Updraft (Ocean, Sc)

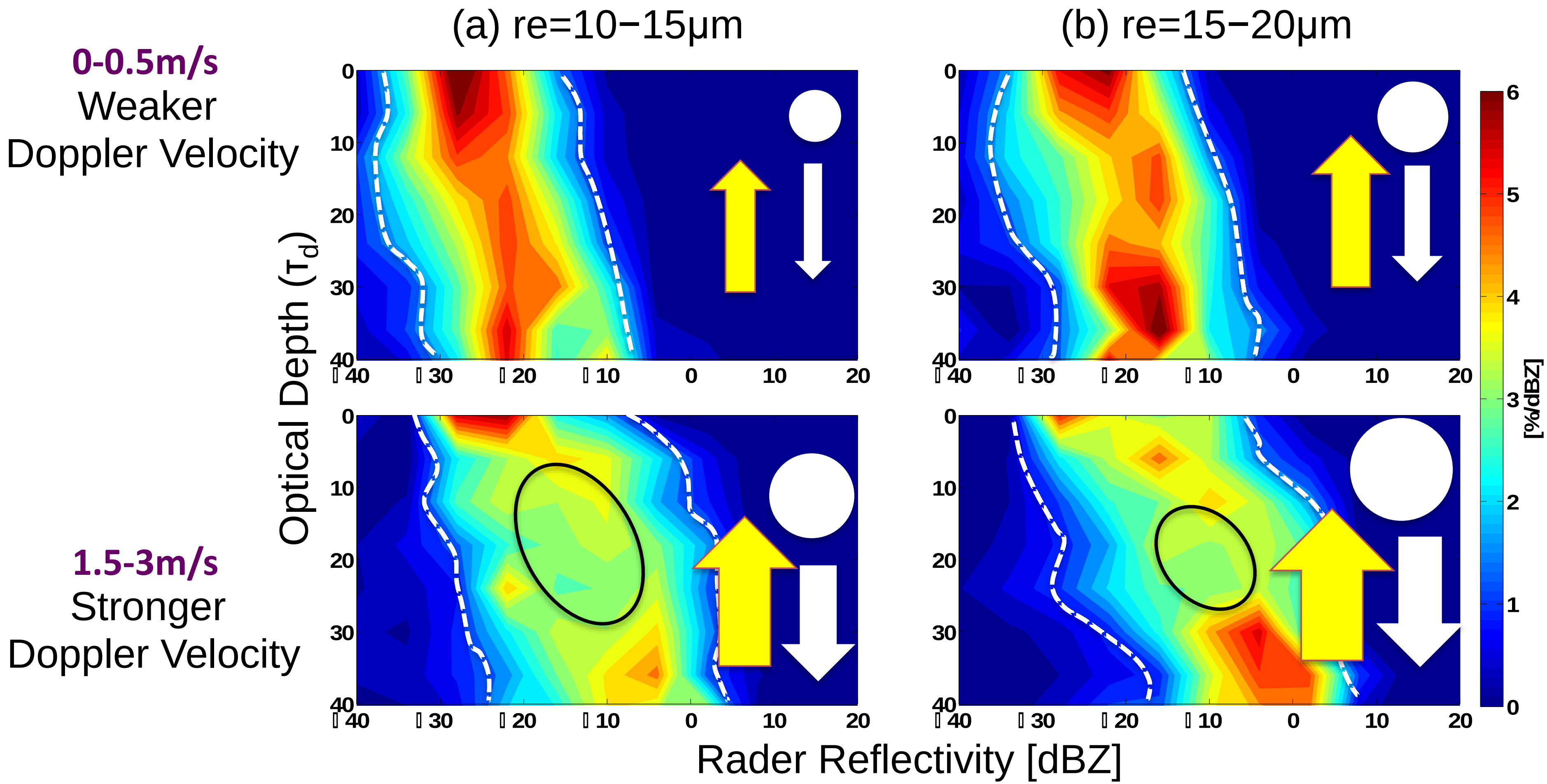


Stronger Updraft (Land, Cu)



- Particles start to fall sooner over ocean.
- Drizzle suppression can be seen over land.

Testing Our Hypothesis II : ARM Ground-Based Measurement



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